

HEAT INSULATING PLUNGER SLEEVE FOR DIE CASTING MACHINES

TECHNICAL FIELD

The present invention relates to heat insulating plunger sleeves for use in die casting machines for casting nonferrous metal products.

BACKGROUND ART

Nonferrous metal products are cast with use of a die casting machine by injecting a molten nonferrous metal, such as aluminum alloy or magnesium alloy, into the cavity of a die through a plunger sleeve under pressure.

FIG. 1 shows a die casting machine plunger sleeve (also termed "shot sleeve") 10, which is used as attached to a die 80 for die casting. The die 80 comprises a stationary die member 82 to which the plunger sleeve 10 is to be attached, and a movable die member (not shown) which can be removably fixed to the stationary die member 82.

The plunger sleeve 10 is in the form of a hollow cylinder and has a hollow portion 12, the base end of which is to be fixed to the die 80 and provides a molten metal outlet 13 communicating with the interior of the die 80. The hollow portion 12 has an outer end with an opening 14 through which a plunger tip 70 advances into the sleeve 10.

The plunger sleeve 10 is provided in its peripheral wall with a molten metal inlet 15 positioned close to the outer end thereof for injecting a molten nonferrous metal into the plunger

sleeve 10 therethrough.

The plunger sleeve 10 is provided at the base end thereof with connecting means 16, such as a flange, for fixing the sleeve 10 to the stationary die member 82.

The molten nonferrous metal is injected into the plunger sleeve 10 through the inlet 15 with the sleeve 10 connected to the die 80 and with the plunger tip 70 advanced into sleeve 10 a small distance from the opening 14. The plunger tip 70 is then pushed toward the die 80, whereby the molten metal is forced into the die 80 for injection casting.

Corrosion resistance to molten metals, thermal shock resistance, plunger tip slidability, and frictional resistance to the sliding of the tip are required of the plunger sleeve 10 for forcing the supply of molten nonferrous metal into the die. Alloy tool steels (JIS-G4404), typical of which is SKD61, are used for the plunger sleeve 10 as materials having these physical properties.

However, a drop in the temperature of the molten nonferrous metal supplied to the plunger sleeve 10 in the casting operation described above, if great, will cause a fault, such as misrun or cold shut, in the casting, presenting difficulty in assuring the casting of a stabilized quality. A drop in the temperature of the molten metal further solidifies the melt on the inner surface of the plunger sleeve 10, causing wear on the plunger tip 70 to entail problems such as an adverse effect on the service life of the plunger tip and an impaired quality of the casting

due to the presence of solid pieces.

Causes of such a temperature drop of the molten nonferrous metal includes the high thermal conductivity of the plunger sleeve 10 (the thermal conductivity of the alloy tool steel SKD61: about 34 W/m·K).

To suppress the temperature drop of the molten nonferrous metal by the plunger sleeve 10, a plunger sleeve 10 is provided which has a sintered ceramic layer 94 between metal layers 90 and 92 as shown in FIG. 7. The provision of the sintered ceramic layer 94 gives improved heat insulating properties to the sleeve 10.

The plunger sleeve 10 shown in FIG. 7 is made by preparing a tube of sintered ceramic body for making the sintered ceramic layer 94 in the form of half segments of the tube, fitting the tube segments around a hollow cylindrical inner metal layer 90 in an annular form, and further fitting around the resulting assembly an outer metal body in the form of divided half segments of a tube.

However, since the metal layers 90, 92 are different from the sintered ceramic layer 94 in coefficient of thermal expansion, a crack, fracture or separation is likely to occur between the metal layer 90 and the ceramic layer 94 when the molten nonferrous metal is injected into the plunger sleeve 10.

DISCLOSURE OF THE INVENTION

An object of the present invention is to provide a heat

insulating plunger sleeve for use in die casting machines which is outstanding in heat insulating and heat-retaining properties and in stability for use as a structural member and which is capable of suppressing the drop in the temperature of molten nonferrous metal to the greatest possible extent and maintaining a stabilized casting operation under pressure.

To accomplish the above object, the present invention provides a heat insulating plunger sleeve for use in die casting machines which comprises a first metal layer made of a metal having high heat resistance and forming an inner periphery of the sleeve, a second metal layer providing an outer periphery of the sleeve, and a ceramic layer formed between the first metal layer and the second metal layer, the ceramic layer comprising a ceramic powder and/or a ceramic fiber consolidated to at least 50% to not greater than 90% in relative density.

The ceramic layer of ceramic powder and/or ceramic fiber as consolidated and provided between the first and second metal layers gives outstanding heat insulating properties to the plunger sleeve. The heat insulating effect produced by the conventional sintered ceramic layer utilizing the low thermal conductivity of a ceramic material is dependent on the thickness of the ceramic layer, and there is a need to increase the thickness of the ceramic layer if the desired heat insulating effect is to be obtained. However, the ceramic layer made by consolidating the ceramic powder and/or ceramic fiber without sintering exhibits exceedingly greater heat insulation than

is expected from the thickness of the ceramic layer. The outstanding heat insulation is thought attributable to heat insulating regions produced because the ceramic power or ceramic fiber is consolidated without sintering and because the interface between the ceramic layer and the first or second metal layer has remarkably high thermal resistance. Because the boundary between the layers has extremely high interfacial thermal resistance, the ceramic layer exhibits exceedingly high heat insulating properties even if having a vary small thickness of up to 2 mm, or up to 1 mm.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing a die casting machine plunger sleeve as it is in use.

FIG. 2 is a view showing a heat insulating plunger sleeve of the invention in section along the axis thereof, for use in die casting machines.

FIG. 3 is a view in section taken along the line III-III in FIG. 2.

FIG. 4 is a diagram showing an example of process for making the heat insulating plunger sleeve of the invention.

FIG. 5 is a sectional view showing another embodiment of the invention.

FIG. 6 is a sectional view of a specimen.

FIG. 7 is a sectional view of a conventional plunger sleeve for use in die casting machines.

BEST MODE OF CARRYING OUT THE INVENTION

The present invention provides a plunger sleeve 10 for use in die casting machines which is characterized in that the sleeve has a ceramic layer 30 comprising a ceramic powder and/or a ceramic fiber consolidated to at least 50% to not greater than 90% in relative density. The term "relative density" is defined as the ratio of the density of the ceramic layer to the true density of the ceramic constituting the ceramic layer.

As shown in FIGS. 2 and 3, the plunger sleeve 10 is fabricated by forming a first metal layer 20 of a metal having high heat resistance on the inner peripheral side, forming around the first metal layer 20 a ceramic layer 30 comprising a ceramic powder and/or a ceramic fiber as consolidated to at least 50% to not greater than 90% in relative density, and forming around the ceramic layer 30 a second metal layer 40 of a metal the same as, or different from, the metal of the first metal layer 20, the layers 20, 30, 40 being in the form of concentric circles.

Although the ceramic layer 30 of the plunger sleeve to be described below has a single-layer structure, a plurality of ceramic layers 30 can be provided in the sleeve as shown in FIG. 5.

Preferably, the first metal layer 20 is made of a metal material which has corrosion resistance to molten nonferrous metals and which is excellent in heat resistance and abrasion resistance. It is desired that the inner periphery of the layer 20 to be exposed to the molten metal be subjected to a nitriding treatment. Examples of useful metals are an alloy comprising

0.32 to 0.42% of C, 0.8 to 1.2% of Si, up to 0.5% of Mn, 4.5 to 5.5% of Cr, 1.0 to 1.6% of Mo, 0.5 to 1.2% of V and the balance substantially Fe, an alloy amenable to nitriding and comprising 0.4 to 0.5% of C, 0.15 to 0.5% of Si, 1.3 to 1.7% of Cr, 0.15 to 0.3% of Mo, 0.7 to 1.2% of Al and the balance substantially Fe, a high-speed steel comprising 0.73 to 0.83% of C, 0.15 to 0.35% of Si, 3.8 to 4.5% of Cr, 17.0 to 19.0% of W, 0.8 to 1.5% of V and the balance substantially Fe, and a semihigh-speed steel comprising 0.4 to 0.7% of C, 0.5 to 2.0% of Si, up to 0.5% of Mn, 4.0 to 6.0% of Cr, 10.0 to 15.0% of W, 0.5 to 1.0% of V and the balance substantially Fe, etc., the proportions of the components being expressed in wt. %. The first metal layer 20 can be made of a sintered metal having a composite structure comprising a matrix of titanium or a titanium alloy and a dispersed phase of titanium carbide incorporated in the matrix. Examples of such sintered metals are a Ti-TiC composite sintered metal comprising a matrix of titanium (Ti) and titanium carbide (TiC) present in the matrix in an area ratio of 20 to 30%, and a Ti alloy-TiC composite sintered metal comprising a matrix of Ti-Mo alloy (containing 20 to 35 wt. % of Mo) and titanium carbide (TiC) present in the matrix in an area ratio of 20 to 30%.

As will be described later, it is advantageous to give a small thickness to the first metal layer 20 insofar as the layer retains a predetermined mechanical strength. It is desired to determine the thickness of the layer 20 in the range

of about 3 to about 15 mm, preferably of about 3 to about 10 mm, in accordance with the overall wall thickness of the plunger sleeve 10 and the inside diameter of the hollow portion 12.

The ceramic layer 30 comprises a ceramic powder or ceramic fiber as consolidated. Examples of ceramic materials usable are oxide, nitride, boride, carbide, silicide ceramics. For example, usable is at least one material selected from the group consisting of Al_2O_3 , $\text{Al}_2\text{O}_3\text{-SiO}_2$, ZrO_2 , SiO_2 , Si_3N_4 , BN, TiB_2 , SiC and MoSi_2 . When different kinds of materials are to be used, these materials may be merely mixed together, or made into a composite material. Preferably, the ceramic powder is 0.5 μm to 100 μm in mean particle size. The ceramic fiber is preferably 1 μm to 20 μm in diameter and 10 μm to 30 mm in length. The ceramic fiber may be used as made into a nonwoven fabric.

It is desired that the ceramic layer 30 be at least 0.1 mm in thickness in order to obtain a predetermined heat insulating effect. However, it is suitable that the thickness be up to 2 mm, preferably up to 1 mm, since too great a thickness is likely to impair the stability of the layered structure. It is more desirable to give a thickness of up to 0.5 mm to the ceramic layer. The ceramic layer 30 having such a small thickness and made from a powdery or fibrous ceramic material as consolidated without being sintered is deformable in conformity with the thermal expansion or thermal contraction of the metal layers 20, 40 that would occur when the plunger

sleeve 10 is fabricated or used, so that the ceramic layer 30 acts as a layer for absorbing and mitigating thermal stress. In order to assure the layered structure of strength and to obtain the specified heat insulating effect, the ceramic layer 30 is suitably at least 50% to not greater than 90%, and preferably at least 70% to not greater than 90%, in relative density.

Although the same material as the first metal layer 20 is usable for the second metal layer 40, corrosion resistance to the molten nonferrous metal is not required of the second metal layer 40 since this layer 40 is held out of direct contact with the melt of the metal. The second metal layer 40 is further insulated from heat by the ceramic layer 30 and therefore need not have high heat resistance unlike the first metal layer 20, nor is abrasion resistance required of the second metal layer 40 since the plunger tip 70 will not slide in contact with this layer 40. Accordingly, S45C or like carbon steel (JIS-G4051) for mechanical structures or SS400 or like common structural steel (JIS-G3101) may be used suitably.

The thickness of the second metal layer 40 is suitably adjusted insofar as the layer retains a predetermined mechanical strength. It is desired to determine the thickness in the range of about 10 to about 50 mm, preferably of about 15 to about 40 mm, in accordance with the overall wall thickness of the plunger sleeve 10 and the inside diameter of the hollow portion 12.

The plunger sleeve 10 is fabricated, for example, by the

process to be described below. With reference to FIG. 4, a second hollow cylinder 42 for making the second metal layer 40 is positioned around a first hollow cylinder 22 for making the first metal layer 20 concentrically with the cylinder 22. The second cylinder 42 has an inside diameter larger than the outside diameter of the first cylinder 22. The plunger sleeve 10 is fabricated by filling a ceramic powder and/or a ceramic fiber into an annular clearance between the first cylinder 22 and the second cylinder 42 and conducting pressure forming work, such as hot isostatic pressing (HIP), hot extrusion or cold isostatic pressing, to apply a working load on the resulting arrangement for pressing from inside the first cylinder 22 and from outside the second cylinder 42. This operation causes the cylinders 22, 42 to press the ceramic powder and/or ceramic fiber between the cylinders 22, 42 for consolidation to form a ceramic layer 30. Unlike sintered ceramics, the ceramic layer 30 is deformable in conformity with the expansion and contraction of the cylinders 22, 42 during the pressure forming work, so that the ceramic layer 30 is given a wavy shape. When the ceramic material is pressed by HIP, an unbonded layer 34 of low adhesion is formed at the boundary between the ceramic layer 30 and the first layer 20. It has been found that this layer 34 has exceedingly high interfacial thermal resistance and therefore gives remarkably improved heat insulating properties.

The assembly obtained by the pressure forming operation

is cut to a predetermined length, and the workpiece obtained is closed at opposite ends with end plates 17, 18 as shown in FIG. 2. One of the end plates, 17, can be in the form of a flange for use as means 16 for connecting the sleeve to a die 80. The workpiece having the end plates 17, 18 attached thereto is suitably machined to form a molten metal inlet 15 and obtain a plunger sleeve 10.

The plunger sleeve 10 described above has a three-layer structure comprising a first metal layer 20, ceramic layer 30 and second metal layer 40, whereas the plunger sleeve 10 can be of the structure shown in FIG. 5. The second metal layer 40 then comprises a plurality of layers 41, 41. Provided between these layers 41, 41 is a ceramic layer 30 comprising a ceramic powder and/or a ceramic fiber as consolidated to at least 50% to not greater than 90% in relative density. The number of ceramic layers 30, 30 can be suitably determined in accordance with the requirements such as heat insulation.

The spacing between the ceramic layers 30, 30, which may be determined also suitably, is preferably not larger than the thickness of the first metal layer 20.

[Example 1]

To check the plunger sleeve 10 of the present invention for heat insulating properties, five flat plate specimens S were fabricated which were altered in the thickness of the ceramic layer and then tested for thermal conductivity. A comparative specimen S' was also prepared which had a sintered

ceramic plate in place of ceramic powder, and similarly tested for thermal conductivity.

With reference to FIG. 6, each of the specimens S1 to S5 was made by forming a recess 54 in a base layer 52 of the same material as the second metal layer 40, filling the recess with a ceramic fiber 56, covering the fiber with a surface layer 58 of the same material as the first metal layer 20, and subjecting the resulting assembly to an HIP treatment. The comparative specimen S' was prepared by placing the sintered ceramic plate between a base layer 52 and a surface layer 58 and pressing the assembly cold on the surface layer side.

The specimen and test conditions are given below.

<Specimens>

-Size: 50 mm in diameter, 19 mm in thickness, 3 mm in surface layer thickness

-Thickness of ceramic layer: S1=0.2 mm, S2=0.3 mm, S3=0.5 mm, S4=0.9 mm, S5=1.5 mm, Thickness of sintered ceramic plate of comparative specimen S'=6 mm

-Material of surface layer: in wt. %, 0.37% of C, 1.0% of Si, 0.4% of Mn, 5.0% of Cr, 1.25% of Mo, 1.0% of V and the balance substantially Fe (34 W/m·K in thermal conductivity)

-Material of base layer: SS400, 42 kg/mm² in tensile strength (59 W/m·K in thermal conductivity)

-Ceramic material: Al₂O₃-SiO₂ fiber

<Thermal conductivity test conditions>

-Measuring method: temperature gradient method

-Measuring direction: direction of thickness of specimen
(with the surface layer side set as high temp. side)

-Measuring temperature: 34-45 °C

-Measuring end temperature difference: 7.9-8.25 °C
(about 14 kW/m² in heat flow per unit area)

-Specimen clamping pressure: about 72 kPa (grease of high thermal conductivity was used at device-specimen interface)

<Result of measurement>

Table 1 shows the measurements of thermal conductivities (α) of the entire specimens (entire wall thickness) and the apparent thermal conductivity (α_i) of the inside layer calculated from the measurement (α) and the thermal conductivities of the specimen component materials according to Fourier's law.

Table 1

Unit: W/m·K

Specimen	Thermal conductivity (α_i) of surface layer (first metal layer)	Thermal conductivity (α) of specimen (entire wall thickness)
S1	3.4 × 10	11.6
S2	3.0 × 10	9.3
S3	2.8 × 10	8.3
S4	2.6 × 10	7.7
S5	2.3 × 10	6.8
S'	2.8 × 10	8.3

Table 1 reveals that the thermal conductivity of the entire specimen S is exceedingly lower than the thermal conductivity (34 W/m·K) of the first metal layer 20 forming the specimen. The specimen is nearly comparable in thermal conductivity to the comparative specimen S' wherein a 6-mm-thick sintered ceramic plate is used.

When a specimen was prepared without forming the ceramic layer, with the surface layer 58 diffusion-bonded to the base layer 52 completely at the entire contact interface thereof (3 mm of surface layer, 16 mm of bases layer and 19 mm in entire wall thickness), the thermal conductivity of the entire specimen as calculated according to Fourier's law was about 52.9 W/m·K. A comparison of this value with the measurements (α) of thermal conductivities given in Table 1 indicates that the ceramic layer 30 produced a very great heat insulating effect.

The specimens S1 to S5 are found to be highly homogeneous in the heat insulating properties of the layer 34 produced between the ceramic layer 30 and the first metal layer 20 and of the overall interface containing the ceramic layer 30, and to be diminished in uneven distribution of heat in the circumferential direction and axial direction and in the strain due to uneven heat distribution.

[Example 2]

Plunger sleeves 10 so shaped as shown in FIGS. 2 and 3 were fabricated by HIP with the ceramic layers 30 thereof given varying thicknesses, and checked for the state of the inner

surface of the first metal layer due to the difference in the thickness of the ceramic layer 30 for evaluation. The same metals and ceramic material as in Example 1 were used.

Given below are the dimensions of the plunger sleeve 10 and HIP conditions.

-First metal layer 20: 150 mm in inside diameter, 7 mm in thickness

-Ceramic layer 30: 1 mm, 2 mm or 3 mm in thickness

-Second metal layer 40: 260 mm in outside diameter

-Plunger sleeve 10: 1000 mm in entire length

-HIP conditions: 1100 atm., 950 °C

The plunger sleeves 10 fabricated were checked for the state of the inner surface with the following result.

Table 2

Thickness of ceramic layer	State of inner surface of first metal layer	Evaluation
1 mm	Precisely circular	◎
2 mm	Nearly circular	○
3 mm	Some indentations	△

Table 2 shows that when having a small thickness (of up to 2 mm), the ceramic layer 30 is subjected to uniform compression in its entirety, permitting the first metal layer 20 to retain a precisely circular or nearly circular inner surface, but that when the ceramic layer has a thickness of 3 mm, local stress

concentration occurs to produce indentations in the first metal layer 20. If indentations occur in the first metal layer 20, the layer may be additionally machined to form a precisely circular inner periphery.

The above result reveals that it is desirable to give the ceramic layer 30 a thickness of up to 2 mm, more preferably up to 1 mm, from the viewpoint of fabrication.

[Example 3]

Fabricated in this example were a plunger sleeve 10 of this invention having a 2-mm-thick ceramic layer 20 and a comparative plunger sleeve having a 6-mm-thick sintered ceramic body 94 (see FIG. 7) with a relative density of 98%. A molten metal ADC12 (Al alloy) having a temperature of 680 °C was injected into the plunger sleeves and used for actual casting.

As a result, even when the plunger sleeve 10 of the invention was used for casting 30,000 shots, the first metal layer 20 still retained the true circularity of its inner surface. This is attributable to the ceramic layer 30 of consolidated material used which mitigated the stress unlike the sintered body when the first metal layer 20 was thermally expanded by the injection of the molten metal.

On the other hand, the comparative shot sleeve developed a crack in the sintered ceramic body 94 upon casting 200 shots and became impaired in the true circularity of the first metal layer 90 and no longer usable for casting. More specifically, the plunger tip 70 became immovable. This malfunction is

attributable to the difference between the sintered ceramic body 94 and the first metal layer 90 in the degree of thermal expansion resulting from the injection of the molten metal.

The result described above indicates that the plunger sleeve 10 of the invention having the ceramic layer 30 has higher durability than the plunger sleeve wherein the sintered ceramic body 94 is used.

INDUSTRIAL APPLICABILITY

The heat insulating plunger sleeve of the invention for use in die casting machines is outstanding in heat insulating and heat-retaining properties and in stability for use as a structural member, capable of suppressing the drop in the temperature of molten nonferrous metal to the greatest possible extent and useful for maintaining a stabilized casting operation under pressure.